

## Comments on Energy Star Program Requirements for Solid State Luminaires

### PARKING GARAGE & CANOPY LUMINAIRES

In the draft requirements for solid state luminaires the DOE has proposed to go beyond simply requiring a certain luminaire efficacy, delving into such areas as (1) the angular light distribution and (2) the total luminous flux for luminaires. The Energy Star is not proposing to certify entire lighting installation plans, e.g., including the choice and arrangement of luminaires in a space.

The problem with the approach the DOE is taking is that the angular distribution and the total luminous flux are interrelated with the mounting height, the layout of luminaires in a space and the required illuminance levels in a space. The DOE is thus addressing an incomplete set of the factors that go into an efficient lighting installation. While a good choice of luminaire power and an angular distribution are necessary conditions for a well designed efficient lighting installation they are not sufficient conditions.

What the DOE is proposing to do by requiring minimum luminaire lumens and minimum lumens in 60°-70° is to introduce unnecessary constraints into the design process. Competent illumination engineers are able to make coordinated choices of luminaire lumen output, angular distribution, mounting height and luminaire layout (including spacing) in order to meet a certain illuminance specification. In fact, as described more fully below, the minimum luminaire lumens and angular zone flux requirements imposed by the Energy Star proposal are **poor** choices that a skilled illumination engineer would not make. The choices imposed by the proposed standard effectively mandate glare problems and/or poor uniformity and/or strong undesirable shadows cast by the luminaires !

Such wide angle batwing beams, as would meet the proposed requirement for minimum percent lumens in the 60°-70° zone are potentially more

problematic in the case of LED based fixtures than they would be in the case of fluorescent luminaires because LEDs are extremely bright sources, whereas fluorescents are diffuse area sources.

The cover letter for the second draft explains that the minimum luminaire light flux is being set at 2000 lumens to match a single fluorescent lamp fixture. There is no valid reason to set a minimum luminaire light flux requirement for LED fixtures based on legacy fluorescent technology and in any case 2000 lumens is too high for a design that conforms with best practices for lighting quality and efficiency.

Fluorescent lighting technology is the old technology with its own limitations and LED lighting technology is the new technology which overcomes many of the limitations. There is no reason to artificially impose limitations of old technology onto new technology. A limitation of fluorescent lamps and other discharge lamps is that the efficiency decreases as a function of lamp power. Hence CFL's are less efficient than T5 or T8 fluorescents. The drop in efficacy is a result of discharge physics. LEDs operate according to solid state physics, not discharge physics and LED fixtures can be readily scaled down to low power without loss of efficiency. Hence when working with the old fluorescent technology an efficiency conscious lighting designer would like to use a higher power linear fluorescent lamp. Parking garage lighting presents a problem for the old technology in that the recommended minimum illuminance level is quite low i.e., 1FC =10.76 lux. It has eluded the standard proposers that the legacy technology (e.g., fluorescent) parking garage lighting is problematic and obviously there should be no attempt to emulate the problematic characteristics of the old technology in the new technology.

It should be noted that parking garage lighting with the old technology is unsatisfactory in that the recommended light levels of 10.7 flux calls for the eyes to adjust to a low level but one is constantly confronted with high intensity glare sources. With the old technology, because of the large optical source size of discharge lamps, one can never strictly control the angular distribution of light, over the wide beam angles that arise as a function of the total lumens and low

illuminance spec, and so the old technology installations suffer from poor uniformity, e.g., max/min ratios of 10-to-1 or 5-to-1. Additionally with the old technology, high angle light coming out of open multi-level parking garages leads to wasted light spill out of the building and light trespass.

Combining the proposed Energy Star standard of a minimum 2000 lumens per luminaire with the IES recommended lighting level for parking garages of 10.76 lux<sup>1</sup> necessarily dictates very wide beam angles, i.e. full beam angles in the range of 140 to 160 degrees (70 to 80 co-latitude). (Narrower beam angles would result in the IES illuminance spec being exceeded, thereby incurring energy costs). Such wide beam angles mean the beam will violate well established good practice for avoiding glare. The generally accepted best practice beam pattern for downlighting is a batwing pattern that peaks at between 40° and 50° and has very low flux above 60°. Note that the proposed requirement of 20% light flux in the 60° to 70° zone also mandates glare problems. Additionally it may be problematic in practice to make optics to produce beams that are as wide as dictated by the proposed spec AND at the same time provide uniform illuminance. (Note that a 150 degree beam providing uniform illuminance would need to produce a luminous intensity that is 57 times higher at 75 degrees than at nadir. It is doubtful that any such optic will ever be made.)

A better solution for parking garages is to take advantage of the fact that low power LED luminaires can be as efficient as high power LED luminaires and to design LEDs luminaires that produce highly uniform illuminance with an angular distribution that conforms to the best practices for down lighting, i.e., an intensity peak in the range of 40 to 55 degrees and very low intensity above 60 degrees. The benefits of the batwing distribution for general illumination have been known at least as far back as the 1930's, and probably earlier. (See attached batwing presentation) In this way both direct glare and veiling reflections will be avoided. Because the illuminance spec for parking garages is low, the total luminous flux of each LED luminaire will be low e.g., ~150 lumens, which is less than 1/10<sup>th</sup> of what the DOE is proposing to mandate.

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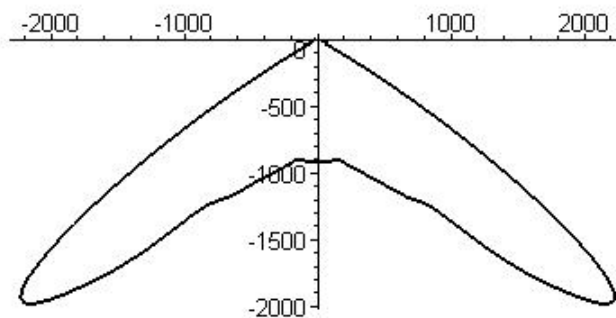
<sup>1</sup> energy parsimony dictates that this should not be greatly exceeded

## EXAMPLE OF HIGH QUALITY ILLUMINATION POSSIBLE WITH LED OPTICS

The graph below shows the illuminance produced by 110° (55° half-angle) batwing secondary lens and a white power LED.<sup>2</sup>

**Fig. 1**

Luminous Intensity (~axisymmetric)- Polar Plot

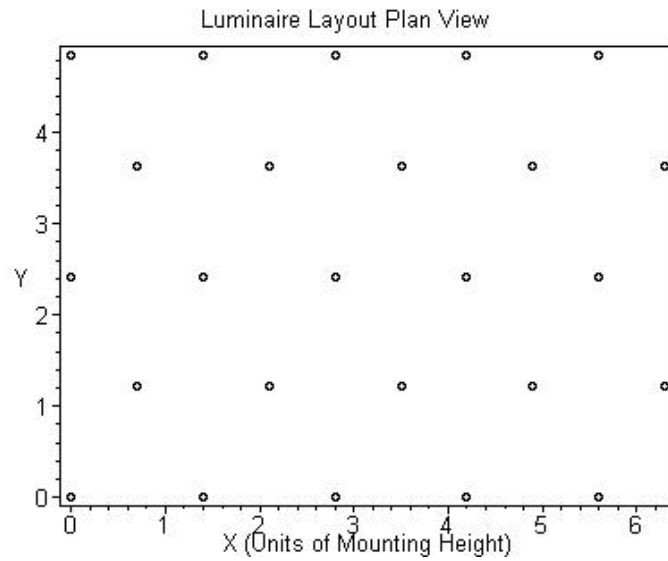


The following graph shows the plan-view layout in an illuminated space (e.g. parking garage) of fixtures based on the 110° batwing secondary lens (both round and semicircle versions). The “effective area” covered by each round beam luminaire is  $1.69 \cdot MH^2$  (MH=Mounting Height)

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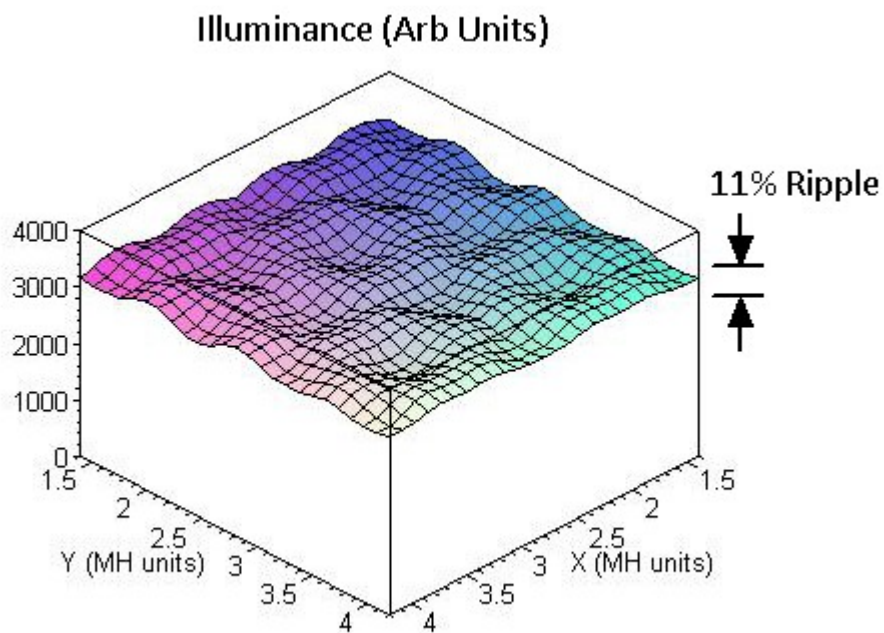
<sup>2</sup> The lens which achieves this distribution is patent pending

**Fig. 2**



The following graph shows the highly uniform illuminance that will be produced by this arrangement.

**Fig. 3**



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## Example Calculation

Application is illumination of large parking garage.

- Assume fixtures will be mounted at 9 ft = **2.74 meters**.
- Assume required lighting level is **10.7 lux** (IES garage lighting spec).
- Based on 11% ripple adjust average lighting level to  
 $10.7 \text{ lux} / 0.945 = \mathbf{11.3 \text{ lux}}$   
(5.5% wasted light above spec)
- Effective area per luminaire is (per above)  $1.69 \cdot 2.74^2 = \mathbf{12.32 \text{ m}^2}$
- Lux required per luminaire is:  
 $11.3 \text{ lux} \cdot 12.32 \text{ m}^2 = \mathbf{139 \text{ lumens}}$ , far less than the **2000 lumens** per fixture mandated by the proposed standard.

## COMMENT ON FITTED-TARGET EFFICACY METRIC

The letter introducing the proposed standard states:

“Two key assumptions underlie the FTE metric. First, relatively rectangular distribution patterns cover most areas more efficiently (with less unnecessary overlap) than rounded distributions. Second, a luminaire’s approximate area of coverage can be defined as the area illuminated to IES-recommended uniformity ratios.” {emphasis added}

The assumptions are ***faulty***. Regarding the first assumption it is noted that circular and semi-circular batwing distributions produced with LED optics can efficiently cover areas (e.g., rectangular areas) either with overlapping or non-overlapping beams. The key is to arrange the luminaires in offset rows as shown in FIG. 2. With substantially non-overlapping beams max-to-min ratios of less than 2-to-1 are achievable. With overlapping beams max-to-min ratios of less than 1.2-to-1 are achievable as illustrated in FIG. 3. I am not aware of any existing rectangular beam optics that when used in either overlapping or non-overlapping arrangement could match these max-to-min ratios on a rectangular target. In the unlikely case that one wishes to cover an entire rectangular area with a single luminaire (e.g., large parking lot with single tower height light pole) the assumption that rectangular beams are superior would be valid, in theory.

Regarding the second assumption, the IES recommended uniformity ratios are based on old technology and should be considered very lax. LEDs are quasi point sources and so high fidelity control of the light distribution can be achieved.

The FTE assumptions characterize overlap as “unnecessary”. In many applications overlap is desirable to avoid strong shadows being cast in the illuminated space so it is wrong to categorize the overlapping arrangement as “unnecessary”. The DOE’s own research has pointed out the problem of strong shadows, see “Lighting with LEDs: Area Lights for Commercial Garage”<sup>3</sup>. It is

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<sup>3</sup> [http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/gateway\\_ppmc\\_brief.pdf](http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/gateway_ppmc_brief.pdf).

recommended practice in many lighting applications to align the edge of one beam pattern (substantially overlapping) with the center of an adjacent luminaire beam pattern thereby ensuring objects are well lit from all sides and no strong shadows are created.

#### ROADWAY AND AREA LIGHTING SHOULD BE ADDRESSED BY SEPARATE STANDARDS

Roadway lighting should be considered distinct from area lighting. In the case of roadway lighting there is an interest in limiting maintenance cost by limiting the number of poles and the illumination target has a high aspect ratio. In this case it is appropriate to call for a rectangular beam pattern and to arrange that the beams are largely non-overlapping .



## PROPOSED STANDARD FOR GENERAL ILLUMINATION LUMINAIRES

I would urge the DOE to adapt a standard that better quantifies how efficiently luminaires provide light when used in an installation with other luminaires and does not unduly constrain illumination engineers. The standard elaborates on the basic idea of “watts/minimum foot candle” that was alluded to by GE Lumination in earlier comments to the DOE. The standard would require Energy Star applicants to provide a “model lighting installation plan” (M-LIP) for each luminaire seeking qualification. The plan which is to be evaluated by a relatively simple software utility would be as follows:

- (1) A specification of the area(s) to be illuminated. This can take the form of one or more ordered lists of coordinates (X,Y,Z) of vertices of the polygon(s) delimiting the area(s). Areas must be rectilinear unless justified by a special lighting application (on an Energy Star approved list to be established). Multiple areas will be allowed only if (1) justified by the fact that different minimum IES illuminance levels apply or (2) to include both at least one vertical surface (e.g., wall) and at least one horizontal surface (e.g., floor). In any case, multiple areas must be contiguous with each other. Allowing non contiguous areas amounts to allowing dark areas. Walls and other vertical surfaces may also be included as areas but must be included in their entirety and illuminance levels on entire walls must meet minimum IES illuminance per item (4). (If no separate IES level exists for walls, value for floors can be substituted) The other option for an applicant is to exclude walls in which case light on walls will be counted toward 10% spill per item (3). This is rational because if light is highly non uniform on walls, it should be considered useless spill. Standard allows for separate illumination of walls (see (7) below).
- (2) Specification of mounting heights and plan view coordinates of luminaires to be used to illuminate area. These can be represented by a list of (X,Y,Z)

coordinates for the set of luminaires. The mounting heights can not be obviously rigged, e.g., CANNOT specify 14ft mounting height for parking garage lighting-note in most cases such a rig would not help poor luminaire design meet the standard.

- (3) 90% of the light emitted by the luminaires must directly illuminate the specified area(s). 10% spill, (e.g., light trespass) allowed. It will be in the applicants interest to limit spill to less than 10% in order to more easily satisfy limit expression given below.
- (4) All points of the area(s) must be illuminated to the IES recommended levels for the primary application (*at least one if there are several*) for which the luminaire is sold, however different IES recommended levels may sometimes apply to individual areas defined in (1). Applicant should cite IES recommended levels that apply to different areas. Applicant will have to come up with a defined area per (1) and luminaire arrangement per (2) that meets (3) and (4).
- (5) The proposed arrangement must satisfy the following energy efficiency expression.

$$E_{Star\_limit} > \frac{\sum Power\ of\ Luminaires}{\sum_{N\ areas} Area \cdot Minimum\ Spec\ Illuminance}$$

- The numerator is the sum of input power of the luminaires in the model lighting installation.
- Sum in denominator is taken over different sub-areas defined in (1) to which different minimum IES recommended illuminance levels apply.
- Total area in denominator is the sum of area(s) specified in (1) which must meet requirements (3) and (4).

- The Minimum Spec Illuminance is the IES recommended level for the primary application for which the luminaire is to be marketed, not the actual minimum illuminance value produced in the arrangement.
  - This means NO credit given for exceeding IES level.
  - Highly non-uniform light distributions will be penalized.

- Suggest initially setting  $E_{\text{Star\_limit}}$  at:

$(1/39) [\text{watts/lumens}] = 1 / (80 \text{ lumens/watt LED efficacy@25 } ^\circ\text{C} * 0.90 \text{ power supply efficiency} * 0.85 \text{ thermal reduction of efficacy} * 0.84 \text{ optical luminaire efficiency} * 0.85 \text{ unwasted lumens on target, lumens not above minimum spec.} * 0.9 \text{ unwasted lumens not spilled out of target area})$

The leading factor (80 lumens/watt) could also be made dependent on the CCT of the LED. The leading factor should be linked to current efficacy of LEDs so as to automatically track LED improvements. Leading factor should be set to include at least 75% of power LEDs being made, or be at 70% of highest bin efficacy LEDs (at 1 Amp per  $\text{mm}^2$ ) that is commercially available, whichever is higher. (Incentivize LED makers to produce LEDs more consistently) A better luminaire design and M-LIP plan will compensate and allow lower bin LEDs to be used, saving cost.

(6) In addition, each luminaire will meet a minimum efficacy standard (e.g., 51 lumens per watt), which may be made dependent on CCT. (Note  $39=51$  times efficiency factors outside luminaire, i.e.,  $0.85*0.9$ )

(7) It will be permitted to combine multiple types of luminaires in the same test. For example luminaires for illuminating the center of spaces, may be combined with luminaires meant to illuminate areas near the wall and optionally the walls, and other luminaires meant to illuminate corners.

(8) If multiple types of luminaires are used, no luminaire will have more than 15% of its light flux contributing to producing illuminance levels that are more than

20% above the IES minimum illuminance level.-i.e., no more than 15% of light flux of each luminaire impinges points where total illuminance is more than 20% above IES minimum spec. In the case of multiple types of luminaires, it is necessary to apply such restrictions to avoid a potential loophole used to qualify generally poor luminaires by combining them in a setup with a good luminaire that dominates the total light flux and power usage.

The DOE could provide a simple software utility to verify that the metric is satisfied. The software utility would read IES files, proposed area(s) (list of (x,y,z) coordinates of polygon vertexes delimiting areas and list of (x,y,z) coordinates of luminaire positions) and calculate the metric. The “model lighting installation plan” (M-LIP) will consist of (1) one or more IES files, (2) a text file which associates each IES file name with an integer n, and then lists (X,Y,Z; n) coordinates for the luminaires corresponding to the IES files, and (3) a text file which indicates minimum illuminance levels for areas and gives ordered sets of (X,Y,Z; k) coordinates of vertices of each kth polygons demarcating the areas. The luminaire arrangement file could look like:

```
1 mylamp_A.IES
2 mylamp_B.IES
1.0,1.0,0.0,1 # comment start specifying locations of 1st type of luminaire
1.0,2.0,0.0, 1
...
2.0,2.5,0.0, 2 #comment start specifying locations of 2nd type of luminaire
3.5,4.0,0.0,2
...
```

The area file with two areas could look like:

```
L 1 500 # comment: specify illuminance level for floor
0,0,0,1 #comment: start defining floor area
0,1,0,1
1,1,0,1
1,0,0,1
L 2 100 #comment: specify illuminance level for wall
0,1,0,2 #comment: start defining adjoining wall area
```

1,1,0,2

1,1,1,2

0,1,1,2

The M-LIP criteria requires luminaire designers to ensure that each luminaire's light distribution is consistent with its power level, intended arrangement in a lighting installation and the IES recommended illuminance levels for the application for which the luminaire is sold. Meeting the criteria calls for competent Illumination Engineering-walking on water will not be required but the mere ability to mount a few LEDs on a heat sink and will not suffice-nor should it. The criteria will ensure that the luminaire is suitable for highly efficient use of electricity for illumination. The E\_star limit is fair and reasonable and is transparently set based on several achievable efficiency factors. The criteria will not place arbitrary constraints on the luminaire designer. The designer is free to choose the total light flux, beam angle & distribution and luminaire layout.

I suggest that the M-LIP standard be published for comment and for an interim period of one year, the Energy Star criteria only require a certain luminaire efficacy, e.g., 50 lumens/watt, which may be made CCT dependent.

### PARKING GARAGES vs. CANOPIES

Finally, Parking Garage and Canopy Luminaires should not be lumped together. Canopies (e.g., service station canopies) typically provide much higher mounting heights for luminaires than parking garages. Requiring a wide light distribution (i.e., having 48% of the luminous flux in the 60-80 zone) for luminaires used for canopy lighting at high mounting heights is basically mandating poor light practice because such an arrangement will lead to high glare and light trespass in the vicinity.

Cordially,  
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